VISIT…

18
Comparison of Synthetic Fluids

Wilfried J. Bartz
Technische Akademie Esslingen
Ostfildern, Germany

I. INTRODUCTION

The conditions of the specific frictional contacts as well as those of the environment have to be taken into account in determining the application of lubricants. Both these influencing factors result in the total complex of requirements to which lubricants are exposed, and all these requirements must be met if an adequate service life is to be obtained. Ranges and limitations of lubricants are controlled by the extent and importance of the individual requirements. If a single requirement exceeds the limits application of a certain fluid, its use will be generally questionable, regardless of whether all other requirements might be met easily.

II. REASONS FOR CHOOSING SYNTHETIC FLUIDS

Regarding the limits of application of fluids, physical and chemical effects have to be distinguished. The physical effects are characterized by temperature and pressure. Figure 1 shows temperature and pressure ranges for certain fields of application for lubricants and operational fluids. Both factors particularly control the so-called liquid range. The solidification of a fluid at low temperatures and high pressures limits its application, as does its evaporation at high temperatures and low pressures.

The chemical effects are characterized by oxidation and radiation influences, both of which are affected by temperature. Figure 2 shows the oxidation, radiation, and temperature ranges for some fields of application for lubricants and operational fluids.

We cannot expect one special or single fluid, such as a mineral oil, to meet the ranges of requirements shown in Figs. 1 and 2. Therefore, it becomes a technical necessity to use synthetic fluids as lubricants and operational fluids.

Two circumstances favor the decision to use a synthetic fluid instead of a mineral oil:

The desired or required property cannot be obtained by mineral oils, even those containing additives.

Copyright © 1999 Marcel Dekker, Inc.

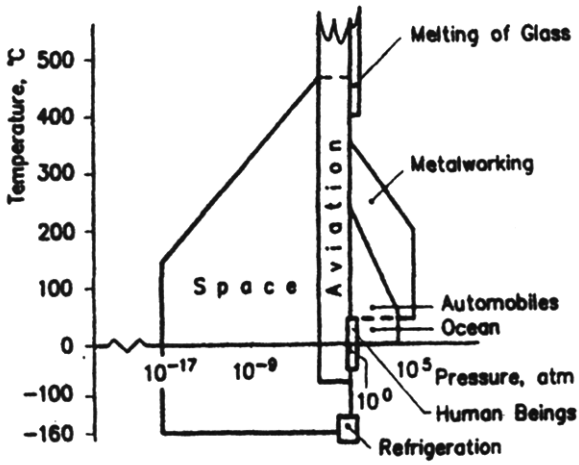

Figure 1 Temperature and pressure ranges for several applications of lubricants and operational fluids.

The extent or quality of the desired or required property cannot be obtained by mineral oils, even those containing additives.

Mineral oils can be inferior to certain synthetic fluids regarding the following properties or property complexes:

thermal stability
oxidation stability viscosity–temperature behavior
flow behavior at low temperatures
volatility at high temperatures
temperature range of application

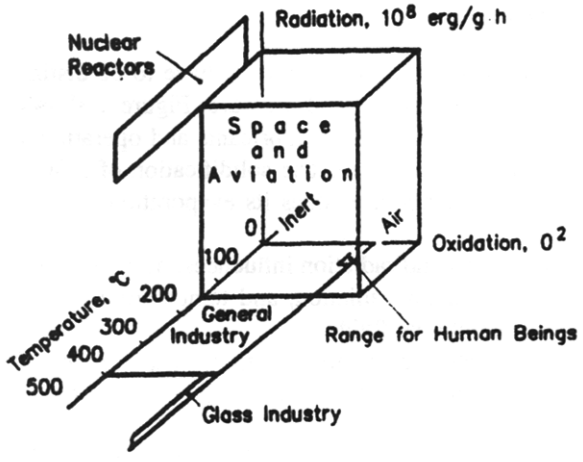

Figure 2 Oxidation, radiation, and temperature ranges for several applications of lubricants and operational fluids.

Copyright © 1999 Marcel Dekker, Inc.

radiation stability
ignition resistance

No synthetic fluid combines all properties in a superior manner to mineral oils. In general, some inferior properties have to be taken into account. Synthetic fluids may compare poorly to mineral oils with respect to the following properties:

hydrolytic behavior
corrosion behavior
toxicological behavior
compatibility with other design materials
miscibility with mineral oil
compatibility with seal materials
additive solubility
availability in general, or in certain viscosity grades
price

Again, it must be stated that no synthetic fluid combines all properties in an inferior manner to those of mineral oils. As a result, some synthetic fluids that exhibit inferior performance in specific applications may have superior performance in other specific areas.

Therefore, the following point of view must also be considered. Certain advantageous properties may be linked inevitably with less adequate properties. For instance, behavior under mixed-film lubrication conditions is strongly controlled by mutual interactions between the lubricant molecules and the surfaces of the frictional contact, which in turn are characterized by the chemical and physical reactivity capability of the fluid. But many synthetic fluids have good chemical and physical stability, hence good oxidation and thermal stability, as well. Rather moderate or even poor behavior at mixed-film lubrication conditions can result.

III. FIELDS OF APPLICATION AND MARKET SHARE

Synthetic and partly synthetic lubricants are used for automotive, aviation, and industry applications. Table 1 shows some of the main fields of application in which synthetic lubricants exhibit advantages against mineral oil-based lubricants. Table 2 reveals the consumption of synthetic and partly synthetic lubricants in the past and projects demand for these lubricants in the future; these figures apply for western Europe. From Table 3 it becomes obvious that the market share of synthetic fluid based lubricants probably will not exceed 7–8% of the total lubricants market.

Table 1 Possible Areas for Applying Synthetic Lubricants

Automotive	Aviation	Industry
Engine oils	Turbine oils	Gas turbine oils
Four-stroke oils	Piston engine oils	Gear oils
Two-stroke oils	Hydraulic fluids	Bearing and circulation oils
Gear oils	Lubricating greases	Compressor oils (gas, air, refrigeration)
Brake fluids		Hydraulic oils
Lubricating greases		Metalworking fluids
		Heat transfer and isolating oils
		Lubricating greases

Copyright © 1999 Marcel Dekker, Inc.

Table 2 Demand in Western Europe for Synthetic Lubricants (1000 tons/yr)

Area of application	1985	1990	1995	2000[a]
Automotive				
Four-stroke engine oils	45	90	130	166
Two-stroke engine oils	3	7	10	10
Gear oils	2	4	6	8
Lubricating greases	6	4	4	6
	56	105	150	190
Aviation				
Turbine oils	9	10	11	13
Piston engine oils	1	2	2	2
Hydraulic oils	1	1	2	3
Lubricating greases	—	—	—	—
	11	13	15	18
Industry				
Gas turbine oils	1	1	1	2
Gear, bearing, and circulating oils	8	15	21	27
Compressor oils	5	10	15	15
Hydraulic oils	23	25	29	34
Metalworking fluids	25	35	40	43
Lubricating greases	2	4	6	7
Heat transfer and isolating oils	1	2	3	4
	65	92	115	132
Total	132	210	280	340

[a]Estimated.

Table 3 Proportion of Total Lubricants Market Devoted to Synthetic Lubricants

1985	1990	1995	2000[a]
<2.0%	3.5%	5.0%	7.0–8.0%

[a]Estimated.

IV. CLASSIFICATION OF SYNTHETIC FLUIDS

Synthetic fluids may be classified based on their chemical composition. Table 4 reveals the basic types of synthetic fluid that can be distinguished [1]. Another criterion of classification, especially for making the distinction between mineral oils and synthetic fluids, is the production process [1]. Mineral oils are produced by distillation and raffination, whereas synthetic fluids are obtained by chemical reactions (Table 5). The chemical structure of synthetic fluids offers a third possibility for their systematic classification [2] (Table 6).

Copyright © 1999 Marcel Dekker, Inc.

Table 4 Classification of Synthetic Fluids According to Chemical Composition

Synthetic fluids	Composition
Synthetic hydrocarbons	C, H
Poly(α-olefins)	
Alkylated aromatics	
Monoalkylbenzenes	
Dialkylbenzenes	
Polyalkylene glycols	C, H, O
Carboxylic acid esters	C, H, O
Dicarboxylic acid esters	
Neopentyl polyesters	
Phosphoric acid esters (phosphate esters)	C, H, O, P
Silicone oils	C, H, O, Si
Silicone oils	
Polysilicone oils (siloxanes)	
Silicate esters	
Polyphenyl ether	C, H, O
Polyfluoroalkyl ether (alkoxyfluoro oils)	C, F, O
Chlorofluorocarbons, chlorotrifluoroethylenes	C, F, Cl
Polymethacrylate/poly(α-olefin) co-oligomers	C, H, O

Table 5 Classification of Mineral Oils and Synthetic Fluids According to Production Process

Mineral oils, produced by distillation and refining		Synthetic fluids, produced by chemical reactions	
Conventional technologies	Modern technologies	Synthetic hydrocarbons	Other synthetic fluids
Acid refining	Hydrotreating	Poly(α-olefins)	Dicarboxylic esters
Solvent extraction	Hydrocracking	Polyisobutenes	Neopentyl polyesters
Dewaxing		Dialkylbenzenes	Polyalkylene glycols
			Phosphate esters
			Silicone oils
			Polyphenyl ether
			Perfluoroalkyl ether
			Chlorofluoroalkyl ether
			PMA/PAO co-oligomers

Copyright © 1999 Marcel Dekker, Inc.

Table 6 Classification of Synthetic Fluids According to Chemical Structure

1. Synthetic hydrocarbons
   - 1.1. Polymers (of olefins)
     - 1.1.1. Ethylene polymers
     - 1.1.2. Propylene polymers
     - 1.1.3. Polybutenes (e.g., polyisobutenes)
     - 1.1.4. Polymers of higher olefins [e.g., poly(α-olefins)]
   - 1.2. Chlorinated hydrocarbons
   - 1.3. Condensation products (of aromatic compounds with olefins) (e.g., polyalkyl and dialkyl aromatics)
   - 1.4. Hydrocracked oils
2. Polyether oils
   - 2.1. Aliphatic polyether (e.g., polyalkylene glycols)
     - 2.2. Perfluoroalkyl ether
     - 2.3. Polythio ether
     - 2.4. Polyphenyl ether
3. Esters, carboxylic acid esters
   - 3.1. Ordinary and complex esters (e.g., dicarboxylic acid esters, complex esters)
   - 3.2. Esters of neopentyl polyols (e.g., neopentyl polyesters)
   - 3.3. Fluorine-containing esters (e.g., fluoroesters, perfluorodialkyl ether)
4. Phosphoric acid esters, phosphate esters
5. Oils containing silicon
   - 5.1. Silicone oils, siloxanes
   - 5.2. Silicic acid esters (e.g., silicate esters)
   - 5.3. Silahydrocarbons (e.g., tetraalkylsilanes)
6. Halogen hydrocarbons, halogen carbons
   - 6.1. Chlorohydrocarbons (e.g., chlorodiphenyls, polychloroparaffins)
   - 6.2. Aliphatic fluoro- and chlorofluorocarbons (e.g., chlorotrifluoroethylene)
   - 6.3. Hexafluorobenzene
7. Others
   - 7.1. Ferrocene derivatives
   - 7.2. Aromatic amines (e.g., triarylamines)
   - 7.3. Heterocyclic N, B, and P compositions
   - 7.4. Urea derivatives
   - 7.5. PMA/PAO co-oligomers

Copyright © 1999 Marcel Dekker, Inc.

V. ADVANTAGES AND DISADVANTAGES OF SYNTHETIC FLUIDS

The advantages and disadvantages of some important synthetic fluids are summarized in Tables 7–15.

1. Synthetic hydrocarbons	
Polyisobutenes	(Table 7)
Poly(α-olefins)	(Table 8)
2. Polyether oils	
Polyalkylene glycols	(Table 9)
Perfluoroalkyl ether	(Table 10)
Polyphenyl ether	(Table 11)
3. Ester oils, carboxylic acid esters; diesters and polyolesters	(Table 12)
4. Phosphate esters	(Table 13)
5. Oils containing silicone and silicone oils	(Table 14)
6. Polymethacrylate/poly(α-olefin) (PMA/PAO)	(Table 15)

Table 7 Advantages and Disadvantages of Polyisobutenes

Advantages
Available in many viscosity grades
Good corrosion behavior
Nontoxic
Clean burning without residues
Good lubricating properties
Miscible in mineral oils and in synthetic hydrocarbons
Disadvantages
Moderate oxidation stability
Higher volatility
Moderate cold flow behavior
Poor viscosity temperature behavior

Copyright © 1999 Marcel Dekker, Inc.

Table 8 Advantages and Disadvantages of Poly(α-olefins)

Advantages
Available in many viscosity grades
Very good cold flow behavior, pour points $< -60°C$
Very low volatility up to $+160°C$, even at low viscosities
High oxidative and thermal stability with oxidation inhibitors
Very good viscosity–temperature behavior
Compatible with mineral-oil-resistant paints
Higher viscous types compatible with mineral-oil-resistant seal materials
Good friction behavior
Unlimited miscibility with mineral oils and esters
Good hydrolytic stability
Good corrosion behavior
No toxic potential owing to absence of aromatic contained in mineral oils
Moderate costs
Disadvantages
Low viscous types have moderate compatibility with a lot of seal materials; compatible with fluorine rubber (FPM) materials
Scuffing and wear protection properties not as good as mineral oils, polyglycols, and esters
Moderate solubility of extreme pressure and antiwear additives
Biological degradation moderate for low viscosity grades, poor for higher viscosity fluids

Table 9 Advantages and Disadvantages of Polyalkylene Glycols

Advantages
Extraordinary high thermal and oxidative stability
Highest chemical stability of all lubricating oils
Very wide service temperature range
Very low volatility
Very good cold flow behavior
Compatible with seal materials, plastics, and paints
Fire resistant
High radiation stability
Good wear and scuffing protecting behavior
Low surface tension; good wetting properties
Disadvantages
Moderate viscosity temperature behavior
Low corrosion protection
No solubility for additives
Not miscible with any other oil
Nontoxic up to decomposition temperature (280–350°C); at higher temperatures toxic decomposition vapors are formed
Extraordinarily high costs

Copyright © 1999 Marcel Dekker, Inc.

Table 10 Advantages and Disadvantages of Perfluoroalkyl Ethers

Advantages
Producible in all viscosity grades desired
Very good viscosity–temperature behavior, high viscosity index
High load-carrying capacity (i.e., good scuffing and wear-protecting properties)
Excellent friction behavior, especially with steel/phosphor bronze contacts
With inhibitors, very good oxidation stability
High service temperatures up to 250°C
Good cold flow properties, low pour point
Good corrosion behavior
Nontoxic
Unbranched polymers with molecular weights up to 1500
Biologically degradable
Disadvantages
In general not miscible with mineral oils, esters, and synthetic hydrocarbons (but some more expensive types are miscible with mineral oils)
Moderate solubility and response for additives
Less pronounced viscosity–pressure behavior compared to mineral oils
Fire resistant only in water solutions
Compatible only with paints based on epoxy resin and polyurea
Compatible only with seal materials based on fluorine rubber (FPM) and polytetraethylene (PTFE) materials; limited compatibility with acrylonitrile–butadiene rubber (NBR) and methyl vinyl silicone rubber (MVQ) materials

Table 11 Advantages and Disadvantages of Polyphenyl Ethers

Advantages
Containing inhibitors: better oxidative and thermal stability compared with mineral oils
High service temperatures
Low pour point, good cold flow behavior
Good viscosity temperature behavior
Unlimited miscibility with mineral oils and most other synthetic oils
Good wear and scuffing protection and friction behavior
Low volatility
Nontoxic
Many types biologically degradable
Mean costs
Disadvantages
Available only in low viscosity grades
Problematical compatibility with seal materials; compatible only with FPM, PTFE, and MFQ materials
No compatibility with paints
Poor hydrolytical stability
Moderate corrosion protection

Copyright © 1999 Marcel Dekker, Inc.

Table 12 Advantages and Disadvantages of Diesters and Polyol Esters

Advantages
Highest thermal and oxidative stability of all lubricating oils
Highest stability against high energy radiation
High chemical stability; highest stability against acids
Excellent lubricating properties, even at mixed-film conditions
Low volatility
Excellent hydrolytical stability
Good miscibility for mineral oils and additives
Disadvantages
Available only in limited viscosity grades
Poorest cold flow behavior of all lubricating oils
Poorest viscosity temperature behavior (negative VI values)
Moderate compatibility with paints
Moderate compatibility with seal materials
Not miscible with perfluoroalkyl ethers, silicone oils, and polyalkylene glycols
Moderate corrosion protection properties
High costs

Table 13 Advantages and Disadvantages of Phosphoric Acid Esters (Phosphate Esters)

Advantages
Fire resistant
Containing inhibitors: good oxidation stability
Good cold flow behavior
Excellent scuffing and wear protection, good friction behavior
Good radiation stability
Triaryl ester types not toxic
Biologically degradable
Disadvantages
Poor viscosity–temperature behavior
Poor hydrolytical stability
Moderate corrosion protection
Compatible only with FPM seal materials
Not miscible with mineral oil

Copyright © 1999 Marcel Dekker, Inc.

Table 14 Advantages and Disadvantages of Silicone Oils

Advantages
Available in many viscosity grades
Best viscosity temperature behavior of all lubricating oils
Very good oxidative and thermal stability
Excellent cold flow behavior
Low volatility, even at low viscosities
High flash points
Compatible with seal materials, plastics, and paints
Corrosion protection properties and hydrolytical stability similar to mineral oil
Good cold flow properties
High chemical stability
Good electrical properties, such as high specific resistance and high dielectric strength (electronic insulation value)
Water insoluble
Disadvantages
Low surface tension, good wetting capacity
Very poor lubricating properties at mixed-film conditions
Lowest load-carrying capacity (wear and scuffing protection), which cannot be improved by additives
Not miscible with mineral oils, synthetic hydrocarbons, esters, polyphenylethers, and perfluoroalkyl ethers
High costs

Table 15 Advantages and Disadvantages of PMA/PAO Co-oligomers

Advantages	Disadvantages
High viscosity index	Low fire resistance
Low evaporation losses	Not biologically degradable
Excellent low temperature behavior	Limited viscosity grades
Good viscosity–temperature behavior	Higher costs
Good oxidation stability	
Excellent compatability with seal material	
Good miscibility with mineral oils and additives	
Nontoxic	

VI COMPARISON OF SOME CHEMICAL, PHYSICAL, AND TECHNOLOGICAL PROPERTIES

Table 16 affords an overall summary review of several chemical and physical properties and some selected technological properties (e.g., indications regarding toxicology, behavior against seal materials and metals, and stability against chemicals) [3].

Copyright © 1999 Marcel Dekker, Inc.

Table 16 Comparison of Properties of Synthetic Lubricating Oils

Property	Diester	Neopentyl polyol (complex) esters	Typical phosphate ester	Typical methyl silicone	Typical phenyl methyl silicone	Chlorinated phenyl methyl silicone	Polyglycol (inhibited)	Chlorinated diphenyl	Silicate ester or disiloxane	Polyphenyl ether	Fluorocarbon	Mineral oil (for comparison)	Remarks
Maximum temperature in absence of oxygen, °C	250	300	120	220	320	305	260	315	300	450	300	200	For esters, this temperature will be higher in the absence of metal.
Maximum temperature in presence of oxygen, °C	210	240	120	180	250	230	200	145	200	320	300	150	This limit is arbitrary. It willdd be higher if oxygen concentration is low and life is short.
Maximum temperature due to decrease in viscosity, °C	150	180	100	200	250	280	200	100	240	150	140	200	With external pressurization temperature or low loads, this limit will be higher.
Minimum temperature due to increase in viscosity, °C	−35	−65	−55	−50	−30	−65	−20	−10	−60	0	−50	0 to −50	This limit depends on the power available to overcome the effect of increased viscosity.
Density, g/mL	0.91	1.01	1.12	0.97	1.06	1.04	1.02	1.42	1.02	1.19	1.95	0.88	
Viscosity index	145	140	0	200	175	195	160	−200 to +25	150	−60	−25	0 to 140	A high viscosity index is desirable.
Resistance to attack by water	Good	Good	Fair	Very good	Very good	Good	Good	Excellent	Poor	Very good	Excellent	Excellent	This refers to breakdown of the fluid itself, not the effect of water on the system.

Copyright © 1999 Marcel Dekker, Inc.

Resistance to chemicals	Attacked by alkali	Attacked by alkali	Attacked by many chemicals	Attacked by strong alkali	Attacked by strong alkali	Attacked by alkali	Attacked by oxidants	Very resistant	Generally poor	Resistant	Resistant but attacked by alkalies and amines	Very resistant	
Effect on metals	Slightly corrosive to nonferrous metals	Corrosive to some nonferrous metals when hot	Enhanced corrosion in presence of water	Noncorrosive	Noncorrosive	Corrosive in presence of water to ferrous metals	Noncorrosive	Some corrosion of copper alloys	Noncorrosive	Noncorrosive	Noncorrosive, but unsafe with aluminum and magnesium	Noncorrosive when pure	
Costs (relative to mineral oil)	5	10	10	25	50	60	5	10	10	250	300	1	These are rough approximations, and vary with quality and supply position.
Flash point, °C	230	255	200	310	290	270	180	180	170	275	None	150 to 200	Above this temperature, the vapor of the fluid may be ignited by an open flame.
Spontaneous ignition temperature	Low	Medium	Very high	High	High	Very high	Medium	Very high	Medium	High	Very high	Low	Above this temperature, the fluid may ignite without any flame being present.
Thermal conductivity, W/m/°c	0.15	0.14	0.13	0.16	0.15	0.15	0.15	0.12	0.15	0.14	0.13	0.13	A high thermal conductivity and high thermal capacity are desirable for effective cooling.
Thermal capacity, J/kg/°C	2000	1700	1600	1550	1550	1550	2000	1200	1700	1750	1350	2000	

Copyright © 1999 Marcel Dekker, Inc.

Table 16 Continued

Property	Diester	Neopentyl polyol (complex) esters	Typical phosphate ester	Typical methyl silicone	Typical phenyl methyl silicone	Chlorinated phenyl methyl silicone	Polyglycol (inhibited)	Chlorinated diphenyl	Silicate ester or disiloxane	Polyphenyl ether	Fluorocarbon	Mineral oil (for comparison)	Remarks
Bulk modulus	Medium	Medium	Medium	Very low	Low	Low	Medium	Medium	Low	Medium	Low	Fairly high	There are four different values of bulk modulus for each fluid, but the relative qualities are consistent.
Boundary lubrication	Good	Good	Very good	Fair but poor for steel on steel	Fair but poor for steel on steel	Good	Very good	Very good	Fair	Fair	Very good	Good	This refers primarily to antiwear properties when some metal contact is occurring.
Toxicity	Slight	Slight	Some toxicity	Nontoxic	Nontoxic	Nontoxic	Believed to be low	Irritant vapor when hot	Slight	Believed to be low	Nontoxic unless overheated	Slight	Specialist advice should always be taken on toxic hazards.
Suitable rubbers	Nitrile, silicone	Silicone	Butyl, EPR	Neoprene, Viton	Neoprene, Viton	Viton, fluorosilicone	Nitrile	Viton	Viton nitrile, fluorosilicone	(None for very high temperatures)	Silicone	Nitrile	
Effect on plastics	May act as plasticizers		Powerful solvent	Slight, but may leach out plasticizers	Slight, but may leach out plasticizers	Slight, but may leach out plasticizers	Generally mild	Powerful solvent	Generally mild	Polyimides satisfactory	Some softening when hot	Generally slight	

Copyright © 1999 Marcel Dekker, Inc.

VII. COMPARISON OF CERTAIN TEMPERATURE-RELATED PROPERTIES

Figure 3 reveals the temperature limits of mineral oils, which are between 100 and 150°C for oxidation and between 350 and 400°C when thermal stability is considered.

The comparatively small influence of oxidation inhibitors added to increase the service temperatures can clearly be recognized. To the extent that oxidation can be avoided, much higher service temperatures can be applied to mineral oils. The limiting temperatures are characterized by the limited thermal stability of the oxidation inhibitors.

The temperature limits of some synthetic fluids are listed in Fig. 4, which plots the temperatures limiting the oxidation and the thermal stability against the service life of the fluid. Obviously, the higher oxidation limit and thermal stability limit of some synthetic fluids result in

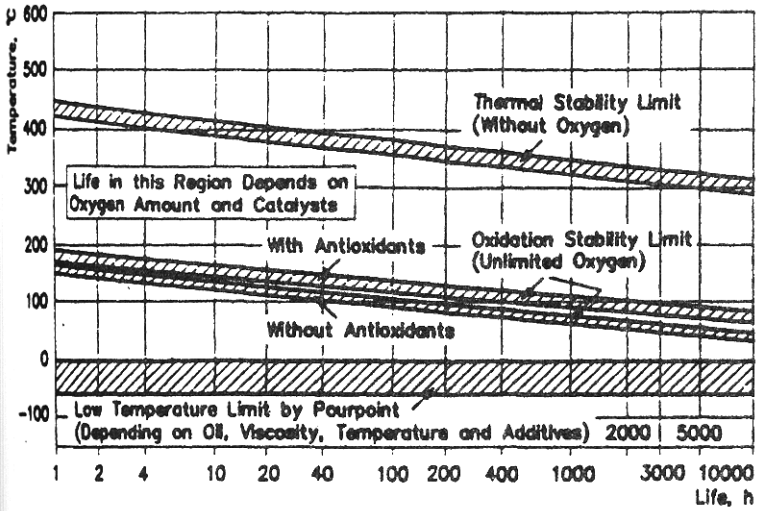

Figure 3 Temperature limits for mineral oils. (From Ref. 3.)

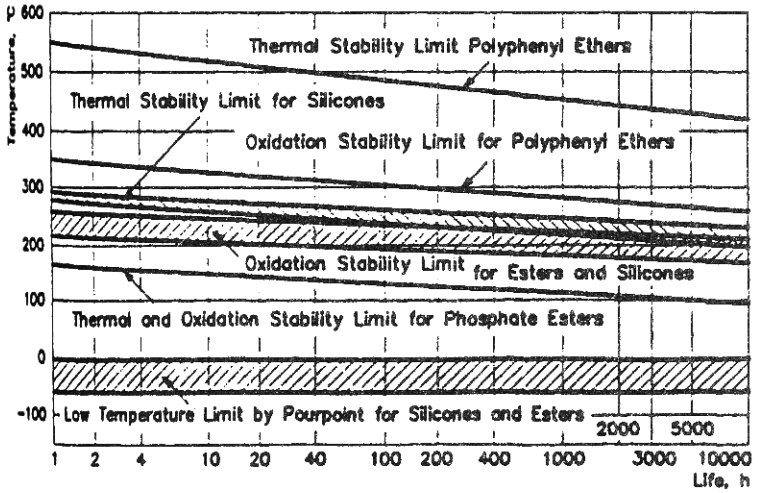

Figure 4 Temperature limits for some synthetic oils. (From Ref. 3.)

Copyright © 1999 Marcel Dekker, Inc.

Table 17 Maximum Service Temperatures for Synthetic Lubricating Oils

Fluid	Temperature (°C)	
	Permanent	Temporary
Mineral oils	90–120	130–150
Synthetic hydrocarbons	170–230	310–340
Carboxylic acid esters	170–180	220–230
Polyalkylene glycols	160–170	200–220
Polyphenyl ether	310–370	420–480
Phosphoric acid esters (alkyl)	90–120	120–150
Phosphoric acid esters (aryl)	150–170	200–230
Silicic acid ester (silicate esters)	180–220	260–280
Silicone oils, siloxanes	220–270	310–340
Silahydrocarbons	170–230	310–340
Halogenated polyphenyls	200–260	280–310
Perfluorohydrocarbons	280–340	400–450
Perfluoropolyglycols	230–260	280–340

better high temperature behavior than is possible with mineral oils. Comparing the behavior of polyphenyl ether with silicone and ester oils illustrates the problematic nature of a situation that can combine excellent high temperature properties with inadequate low temperature behavior. The extraordinary high temperature performance of polyphenyl ether becomes obvious, whereas the very low pour points of silicone oils and esters relegate these fluids to low temperature applications. These relations result in the set of maximum service temperatures for endurance and temporary service periods given in Table 17, and it becomes obvious that some synthetic fluids are superior to mineral oils. In principle, the same statement is valid with regard to service at low temperatures (Table 18). Of course, any direct comparison of fluids of different classes can be made only for fluids having the same viscosity.

These results can be summarized by comparing the service temperature ranges of some

Table 18 Flash Points and Pour Points of Some Synthetic Lubricating Oils

Fluid	Temperature (°C)	
	Flash point	Pour point
Mineral oils	200–300	0 to −60
Poly(α-olefins)	200–350	−20 to −60
Polyalkylene glycols	200–260	−30 to −50
Perfluoralkyl ether	—	−20 to −75
Polyphenyl ether	230–350	+20 to −20
Diesters	200–270	−50 to −80
Phosphate esters	100–260	−10 to −60
Silicone oils	230–330	−10 to −100
Silahydrocarbons	270–290	−5 to −15
Silicate esters	180–280	−50 to −70

Copyright © 1999 Marcel Dekker, Inc.

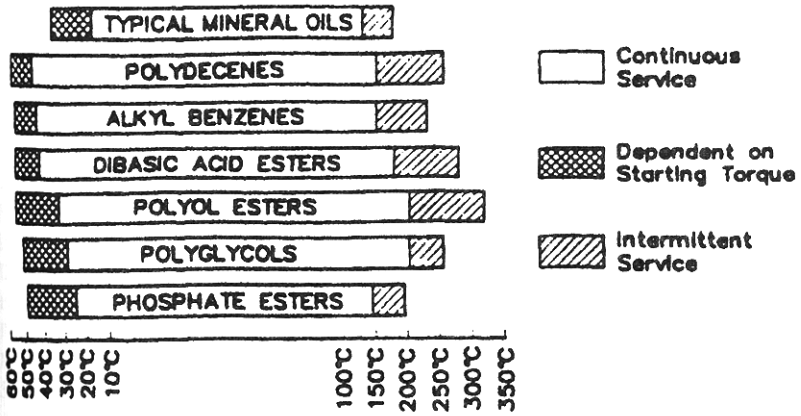

Figure 5 Comparison of service temperature ranges of synthetic fluids. (From Ref. 3.)

synthetic fluids (Fig. 5). Their superiority to mineral oils can clearly be recognized [4]. The temperatures that in general can be applied to synthetic fluids containing adequate oxidation inhibitors are notably higher than those for mineral oils (Fig. 6).

Figure 7 compares the viscosity–temperature behavior of some synthetic fluids and formulations based on mineral oil. Comparison of curves E and F reveals the extent of improvement achievable by using additives in mineral oils. For further improvements, other fluids must be selected (see, e.g., curve B). It is obvious that the excellent viscosity–temperature behavior of a silicone oil cannot be realized with mineral oils, regardless of whether the latter contain viscosity index improvers.

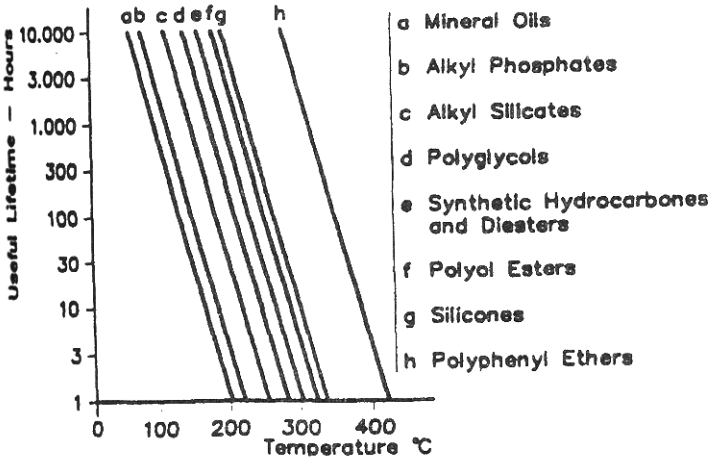

Figure 6 Service life depending on temperature for different synthetic oils containing inhibitors. (From Ref. 3.)

Copyright © 1999 Marcel Dekker, Inc.

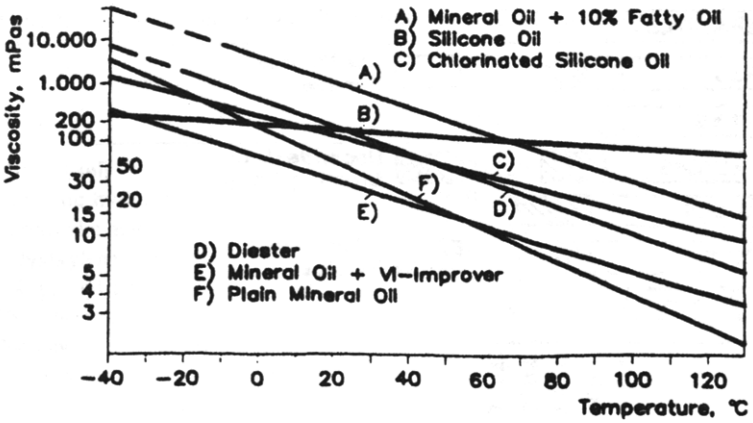

Figure 7 Viscosity–temperature behavior of some lubricating oils.

VIII. COMPARISON OF SOME PROPERTY GROUPS

For application reasons, comparison of certain property groups seems to be the most useful way to select the optimum synthetic fluid to cover the requirements of special tribological contacts. This comparison is done for stability, viscosity, and lubricity properties.

Table 19 simultaneously compares thermal, oxidation, hydrolytic, and volatility behaviors of synthetic fluids and of mineral oil. Hardly any single fluid exhibits excellent, or at least very good behavior, regarding all four properties. Table 20 makes a similar comparison of low temperature fluidity, viscosity index, and pressure viscosity properties. Poly(α-olefins), esters and some silicone-containing fluids reveal very good or even excellent behavior on all properties compared. Table 21 compares wear protection properties, without and with additives, and fatigue life behavior. Again, it is obvious that no single fluid can give very good or even excellent coverage to all requirements simultaneously.

Table 19 Relative Evaluation of Stability Properties of Different Synthetic Fluids

	Properties			
Product	Thermal	Oxidation	Hydrolytic	Volatility
Mineral oil (paraffinic)	Good	Fair	Excellent	Poor/fair
Poly(α-olefins)	Very good	Very good	Excellent	Very good
Diesters	Good	Very good	Fair	Good
Polyol esters	Good	Very good	Fair	Good
Polyalkylene glycols	Good	Good	Good	Good
Phosphate esters	Fair	Good	Fair	Fair/good
Silicones	Very good	Good	Excellent	Excellent
Alkylbenzenes	Good	Good	Excellent	Good
Fluorocarbons	Excellent	Excellent	Good	Poor
Polyphenyl ethers	Excellent	Good	Excellent	Good
Silicate esters	Very good	Good	Fair/poor	Good
Silahydrocarbons	Excellent	Very good	Excellent	—

Copyright © 1999 Marcel Dekker, Inc.

Table 20 Relative Evaluation of Viscosity Properties of Different Synthetic Fluids

Product	Properties		
	Low temperature fluidity	Viscosity index	Pressure–viscosity
Mineral oil (paraffinic)	Fair/good	Good	Good
Poly(α-olefins)	Excellent	Very good	Good
Diesters	Very good	Very good	Very good
Polyol esters	Very good	Very good	Very good
Polyalkylene glycols	Very good	Very good	Very good
Phosphate esters	Fair[a]/good	Fair[a]/good	Very good
Silicones	Very good	Excellent	Excellent
Alkylbenzenes	Good	Very good	Good
Fluorocarbons	Fair	Fair	Fair
Polyphenyl ethers	Poor	Fair	Poor
Silicate esters	Excellent	Excellent	Very good
Silahydrocarbons	Excellent	Excellent	—

[a]Triaryl phosphates have poorer VIs and lower temperature fluidity than trialkyl phosphates.

Table 21 Relative Evaluation of Lubricity (Wear Protection and Fatigue) of Different Synthetic Fluids

Product	Properties		
	Natural lubricity and antiwear	Antiwear with additives	Fatigue life
Mineral oil (paraffinic)	Good	Excellent	Fair/good
Poly(α-olefins)	Good	Excellent	Good
Diesters	Fair	Good	Fair
Polyol esters	Fair	Good	Fair/good
Polyalkylene glycols	Good	Good	Fair
Phosphate esters[a]	Excellent	Excellent	Fair
Silicones	Poor	Fair	Fair/good
Alkylbenzenes	Good	Excellent	Good
Fluorocarbons	Fair/good	Good	Fair/good
Polyphenyl ethers	Good	Good	Good
Silicate esters	Good	Very good	Poor

[a]Acid phosphate esters have excellent antiwear properties but poor fatigue life.

IX. OVERALL COMPARISON OF SYNTHETIC FLUIDS

Table 22 shows an overall comparison of some important physical, chemical, and technological properties of the most important synthetic fluids [2,5,6]. While desirable, the realization of such an overall comparison is difficult, considering the aim of a valid evaluation. Therefore, since

Copyright © 1999 Marcel Dekker, Inc.

Table 22 Comparison of Properties of Important Synthetic Fluids

Property	Evaluations[a]																			
	Mineral oils	Polyisobutenes	Poly(α-olefins)	Alkylated aromates	Polyalkylene glycols	Perfluoroalkyl ethers	Polyphenyl ethers	Dicarboxylic acid esters	Neopentyl polyesters	Triaryl phosphate esters	Trialkyl phosphate esters	Silicone oils	Silicate esters	Silahydrocarbons	Chlorofluorocarbons	Cyclophosphazene fluids	Dialkylcarbonates	Alkylated cyclopentanes	PMA/PAO co-oligomers	Rapeseed oils
Viscosity–temperature behavior (VI)	4	5	2	4	2	4	5	2	2	5	1	1	1	2	4	5	3	3	2	2
Low temperature behavior (pour point)	5	4	1	3	3	3	5	1	2	4	1	1	2	3	3	3	3	3	2	3
Liquid range	4	5	2	3	3	1	5	2	2	2	3	1	1	2	5	4/5	2	1	2	3
Oxidation stability	4	4	2	4	3	1	2	2/3	2	2	4	2	2	3	1	3	2	2	2	5
Thermal stability	4	4	4	4	3	1	1	3	2	2	3	2	3	2	2	3/4	3	4	3	4
Evaporation losses, volatility	4	4	2	3	3	1	3	1	1	2	2	2	3	2	3	3	4	1	1	3
Fire resistance, inflammability temperature	5	5	5	5	4	1	4	4	4	1/2	1/2	3	4	4	1	1/2	3	5	4/5	5
Hydrolytical stability	1	1	1	1	3	1	1	4	4	4	3	3	4	1	2	3	3	1	2	5
Corrosion protection properties	1	1	1	1	3	5	4	4	4	4	4	3	5	1	5	3	1	1	2	1
Seal material compatibility	3	3	2	3	3	1	3	4	4	5	5	3	3	2	4	3/4	3	2	1	4
Paint and lacquer compatibility	1	1	1	1	4	2	4	4	4	5	5	3	4	1	3	3/4	2	1	1	4
Miscibility with mineral oil	—	1	1	1	5	5	3	2	2	4	4	5	4	1	5	5	2	1	1	1
Solubility of additives	1	1	2	1	4	5	2	2	2	1	1	5	3	3	5	4	2	3	1	3
Lubricating properties, load-carrying capacity	3	3	3	3	2	1	1	2	2	1	3	5	4	3	1	2/3	2	3	2	1
Toxicity	3	1	1	5	3	1	3	3	3	4/5	4/5	1	4	2	2	2	1	1	1	1
Biodegradability	4	5	5	5	1/2	5	5	1/2	1/2	2	2	5	4	5	5	—	1	5	4/5	1
Price compared with mineral oil	—	3–5	3–5	3–5	6–10	500	200–500	4–10	4–10	5–10	5–10	30–100	20–30	30–70	300–400	30–50	4–10	3–8	5–10	2–3

[a]1, excellent; 2, very good; 3, good; 4, moderate; 5, poor.

Copyright © 1999 Marcel Dekker, Inc.

several fluids are commercial while others are under development, some introductory remarks are necessary. In addition, there are various subclasses within some general classes, a fact that could not be considered in constructing the table. Under the circumstances, then, this type of comparison may be misleading at the present time.

The same restrictions apply to the influence of additives on the changes of some properties. Last but not least, the ratings between "excellent" and "poor" need some explanation. For instance, a fluid was rated as "excellent" if it was nontoxic. To give another example, the cyclophosphazene fluids could not be rated regarding biodegradability.

Many authors of specific chapters of this book gave valuable assistance in the making of this table, which should be used to obtain a first impression of the properties of synthetic fluids relative to each other. Alkylated cyclopentanes were omitted from this table, because no information about these fluids could be obtained. On the other hand, the properties of rapeseed oils were included. It can be seen that regarding all properties compared, no fluid is superior to mineral oil or would obtain the best evaluation for every property. Particularly, when compared with mineral oils containing additives, synthetic fluids are not superior in all cases.

As a rule, a synthetic fluid is chosen because it has particular performance characteristics that are not obtainable with mineral oils. Lubricating and functional fluids are chosen to cover the requirements of specific applications. Therefore, the fluid of choice for one application may be totally inadequate for another.

If certain applications require special properties that cannot be obtained by using mineral oils, a certain synthetic fluid will have to be selected and applied in spite of some less good or even disadvantageous properties. Every single property, therefore, has to be supplemented by a weighting factor that depends on the application at hand.

X. ALLOCATION OF PROPERTIES TO FIELDS OF APPLICATION

The decision to use synthetic lubricants strongly depends on their specific properties, especially compared to those of mineral oils. Taking this point of view, the advantageous properties favor applications for which requirements relating to frictional contacts cannot be covered by mineral oils. On the other hand, some predominant disadvantages of certain synthetic fluids will exclude them from certain specific fields of application. This allocation of properties to applications is done for the following fluids:

Poly(α-olefins) (Fig. 8)
Polybutenes (Fig. 9)
Polyalkyleneglycols (Fig. 10)
Diesters and polyolesters (Fig. 11)
Phosphate esters (Fig. 12)
Perfluoralkyl ethers (Fig. 13)
Silicone oils (Fig. 14)
Polyphenyl ethers (Fig. 15)

To summarize this allocation, Table 23 shows the main fields of application for the most important synthetic lubricants.

Copyright © 1999 Marcel Dekker, Inc.

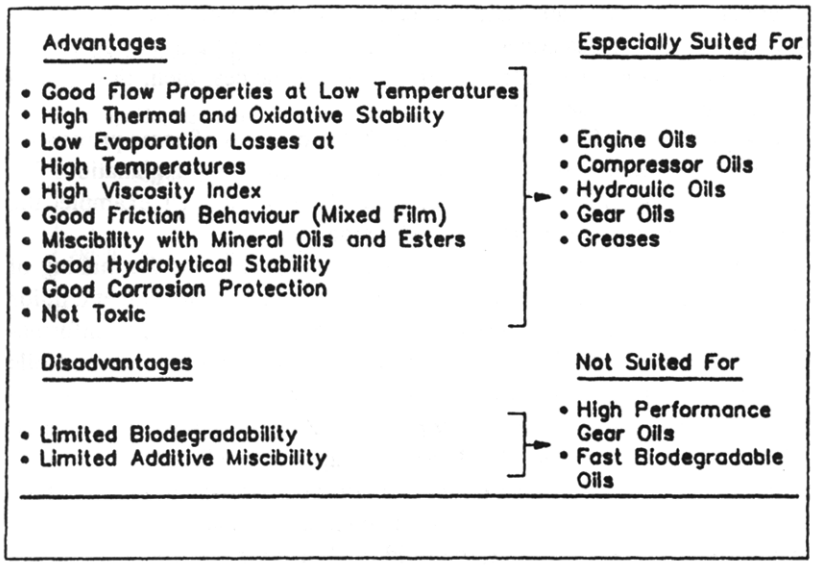

Figure 8 Poly(α-olefins).

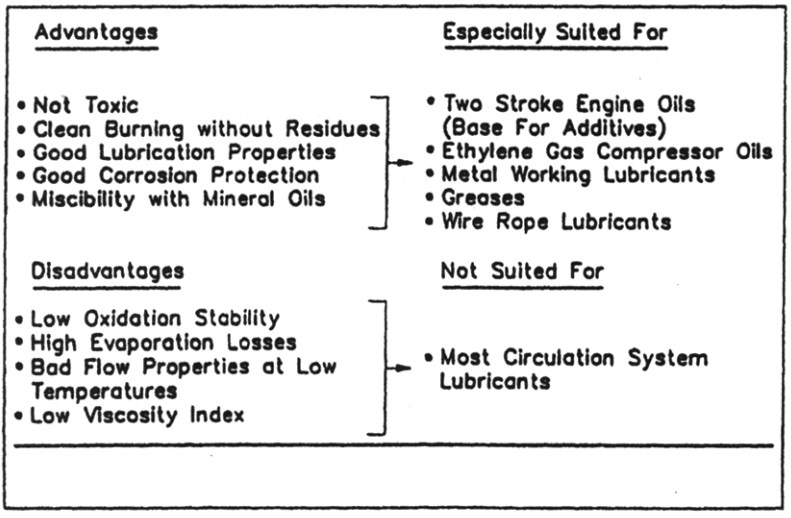
Advantages
Especially Suited For
• Not Toxic
• Clean Burning without Residues
• Good Lubrication Properties
• Good Corrosion Protection
• Miscibility with Mineral Oils
• Two Stroke Engine Oils (Base For Additives)
• Ethylene Gas Compressor Oils
• Metal Working Lubricants
• Greases
• Wire Rope Lubricants
Disadvantages
Not Suited For
• Low Oxidation Stability
• High Evaporation Losses
• Bad Flow Properties at Low Temperatures
• Low Viscosity Index
• Most Circulation System Lubricants

Figure 9 Polybutenes.

Copyright © 1999 Marcel Dekker, Inc.

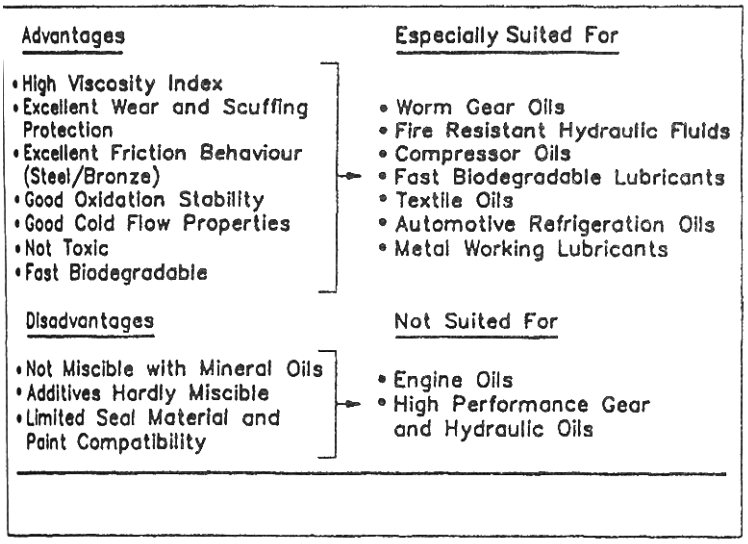
Advantages
• High Viscosity Index
• Excellent Wear and Scuffing Protection
• Excellent Friction Behaviour (Steel/Bronze)
• Good Oxidation Stability
• Good Cold Flow Properties
• Not Toxic
• Fast Biodegradable
Especially Suited For
• Worm Gear Oils
• Fire Resistant Hydraulic Fluids
• Compressor Oils
• Fast Biodegradable Lubricants
• Textile Oils
• Automotive Refrigeration Oils
• Metal Working Lubricants
Disadvantages
• Not Miscible with Mineral Oils
• Additives Hardly Miscible
• Limited Seal Material and Paint Compatibility
Not Suited For
• Engine Oils
• High Performance Gear and Hydraulic Oils

Figure 10 Polyalkylene glycols.

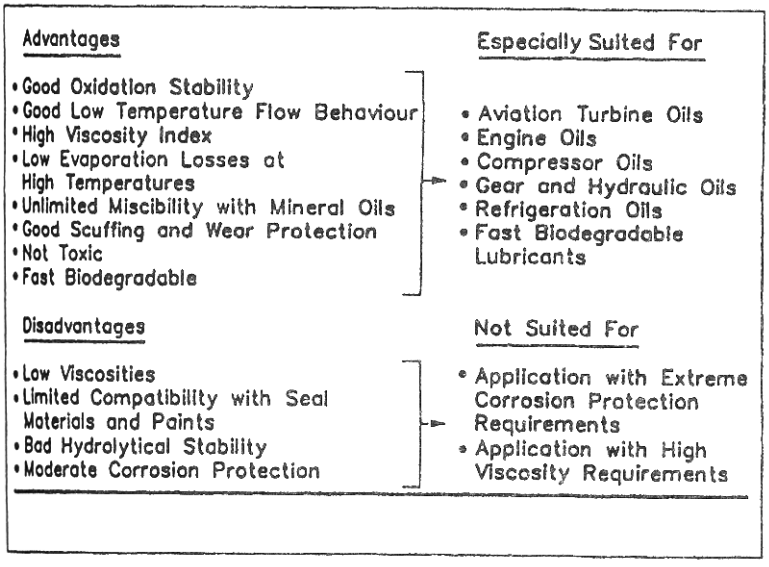
Advantages
• Good Oxidation Stability
• Good Low Temperature Flow Behaviour
• High Viscosity Index
• Low Evaporation Losses at High Temperatures
• Unlimited Miscibility with Mineral Oils
• Good Scuffing and Wear Protection
• Not Toxic
• Fast Biodegradable
Especially Suited For
• Aviation Turbine Oils
• Engine Oils
• Compressor Oils
• Gear and Hydraulic Oils
• Refrigeration Oils
• Fast Biodegradable Lubricants
Disadvantages
• Low Viscosities
• Limited Compatibility with Seal Materials and Paints
• Bad Hydrolytical Stability
• Moderate Corrosion Protection
Not Suited For
• Application with Extreme Corrosion Protection Requirements
• Application with High Viscosity Requirements

Figure 11 Diesters and polyolesters.

Copyright © 1999 Marcel Dekker, Inc.

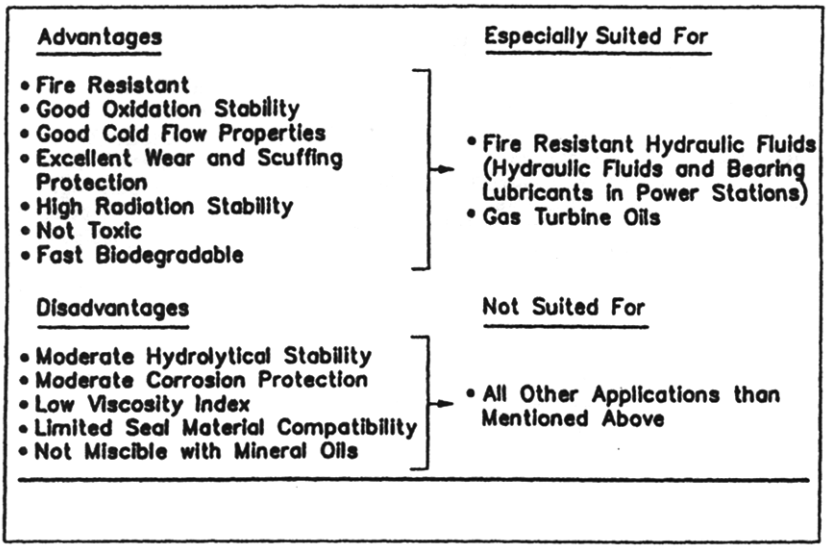
Advantages
• Fire Resistant
• Good Oxidation Stability
• Good Cold Flow Properties
• Excellent Wear and Scuffing Protection
• High Radiation Stability
• Not Toxic
• Fast Biodegradable
Especially Suited For
• Fire Resistant Hydraulic Fluids (Hydraulic Fluids and Bearing Lubricants in Power Stations)
• Gas Turbine Oils
Disadvantages
• Moderate Hydrolytical Stability
• Moderate Corrosion Protection
• Low Viscosity Index
• Limited Seal Material Compatibility
• Not Miscible with Mineral Oils
Not Suited For
• All Other Applications than Mentioned Above

Figure 12 Phosphate esters.

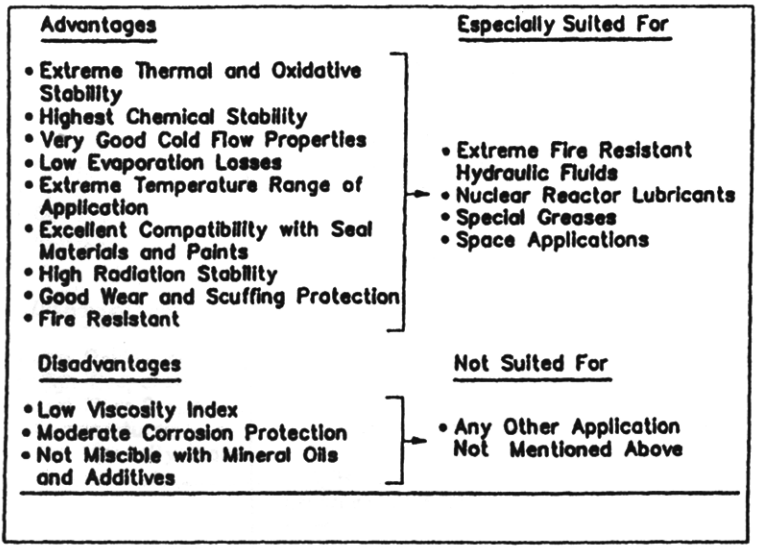
Advantages
• Extreme Thermal and Oxidative Stability
• Highest Chemical Stability
• Very Good Cold Flow Properties
• Low Evaporation Losses
• Extreme Temperature Range of Application
• Excellent Compatibility with Seal Materials and Paints
• High Radiation Stability
• Good Wear and Scuffing Protection
• Fire Resistant
Especially Suited For
• Extreme Fire Resistant Hydraulic Fluids
• Nuclear Reactor Lubricants
• Special Greases
• Space Applications
Disadvantages
• Low Viscosity Index
• Moderate Corrosion Protection
• Not Miscible with Mineral Oils and Additives
Not Suited For
• Any Other Application Not Mentioned Above

Figure 13 Perfluoroalkyl ethers.

Copyright © 1999 Marcel Dekker, Inc.

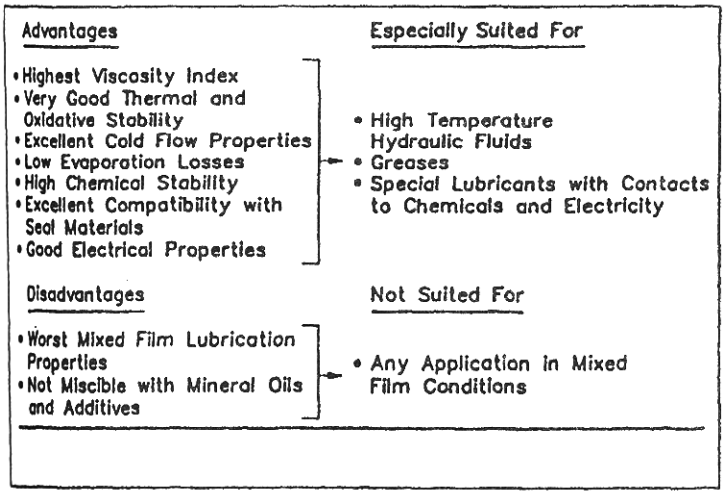
Advantages
Especially Suited For
• Highest Viscosity Index
• Very Good Thermal and Oxidative Stability
• Excellent Cold Flow Properties
• Low Evaporation Losses
• High Chemical Stability
• Excellent Compatibility with Seal Materials
• Good Electrical Properties
• High Temperature Hydraulic Fluids
• Greases
• Special Lubricants with Contacts to Chemicals and Electricity
Disadvantages
Not Suited For
• Worst Mixed Film Lubrication Properties
• Not Miscible with Mineral Oils and Additives
• Any Application in Mixed Film Conditions

Figure 14 Silicone oils (siloxanes).

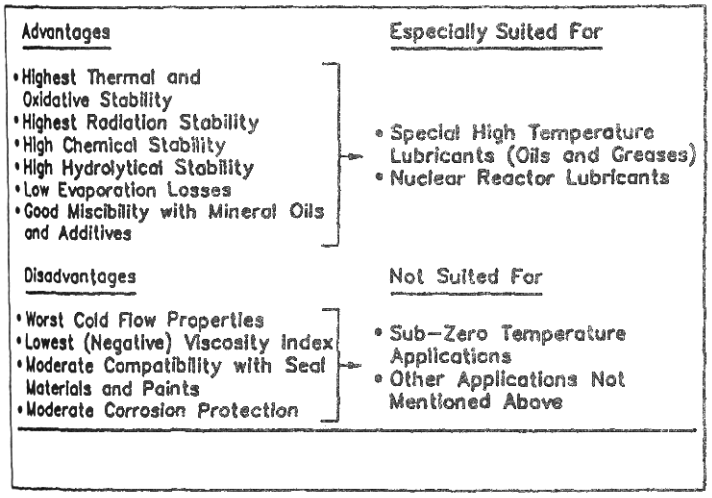
Advantages
Especially Suited For
• Highest Thermal and Oxidative Stability
• Highest Radiation Stability
• High Chemical Stability
• High Hydrolytical Stability
• Low Evaporation Losses
• Good Miscibility with Mineral Oils and Additives
• Special High Temperature Lubricants (Oils and Greases)
• Nuclear Reactor Lubricants
Disadvantages
Not Suited For
• Worst Cold Flow Properties
• Lowest (Negative) Viscosity Index
• Moderate Compatibility with Seal Materials and Paints
• Moderate Corrosion Protection
• Sub-Zero Temperature Applications
• Other Applications Not Mentioned Above

Figure 15 Polyphenyl ethers.

Copyright © 1999 Marcel Dekker, Inc.

Table 23 Important Synthetic Oils and Their Applications

Synthetic oil type	Main applications
Synthetic hydrocarbons	
Poly(α-olefins)	*Engine oils*, industrial lubricants (compressor, hydraulic, and bearing oils)
Polyisobutenes	Metal-forming oils, *two-stroke engine oils*, electrical isolation oils
Alkylated aromatics	*Low temperature oils* for gears, engines, hydraulics
Cycloaliphates	Friction gear oils (due to high coefficient of friction)
Organic esters	
Diesters	Turbine oils, *mixing components for poly(α-olefins)*
Polyolesters	*Turbine oils*, compressor, hydraulic, and gear oils
Polyglycols	
Water soluble	Brake fluids, metalworking oils, *worm gear oils, fire-resistant hydraulic fluids*
Non–water soluble	Worm gear oils
Others	
Phosphate esters	*Fire-resistant hydraulic fluids*, gas turbine oils
Silicone oils	*High temperature hydraulic fluids*, brake fluids, compressor oils
Halogenated fluids	*Extremely fire-resistant hydraulic oils*
Polyphenyl ethers	*Radiation-resistant lubricants*, heat transfer fluids

XI. CONCLUSION

Mineral oils cannot meet all requirements for frictional contacts imposed by applications as lubricants or as operational fluids. As a result, certain synthetic fluids have gained significant importance. These fluids can be classified either by production process, composition, or chemical structure. This chapter used the tabular form to present the chemical, physical, and technological properties of the synthetic fluids as well as the advantages and disadvantages of some important synthetic fluids.

An overall comparison with reference to mineral oils shows that synthetic fluids are superior to mineral oils only in certain properties. To obtain a practical overall comparison, therefore, weighting factors must be applied to the special properties of fluids. Table 23 summarizes the possibilities of synthetic lubricants, by listing information on the main applications of some of the most important fluids.

REFERENCES

1. Bartz, W. J., Notwendigkeiten für den Einsatz synthetischer Schmierstoffe und Betriebsflüssigkeiten (Necessities for the application of synthetic lubricants and functional fluids), *Tribol. Schmierungstechnik, 34,* 262–269 (1987).
2. Klamann, D., *Schmierstoffe und verwandte Produkte* (*Lubricants and related products*), Verlag Chemie, Weinheim, 1982.
3. Neale, M. J., ed., *Tribology Handbook*, Butterworth, London, 1973.
4. Williamson, G. I., Synthetic lubricants—The state of market development and inter-product competition, Course SP5, The College of Petroleum Studies, Oxford, Dec. 5–6, 1988.
5. Schmid, W., *Synthetische Industrieschmierstoffe* (*Synthetic Industrial Lubricants*), Mobil Oil, Hamburg, 1980.
6. Möller, U. J., and Boor, U., *Schmierstoffe im Betrieb* (*Application of Lubricants*), VDI-Verlag, Düsseldorf, 1987.

Copyright © 1999 Marcel Dekker, Inc.